Big Sagebrush (*Artemisia Tridentata*) Communities – Ecology, Importance and Restoration Potential

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Abstract

Big sagebrush (*Artemisia tridentata* Nutt.) is the most common and widespread sagebrush species in the Intermountain region. Climatic patterns, elevation gradients, soil characteristics and fire are among the factors regulating the distribution of its three major subspecies. Each of these subspecies is considered a topographic climax dominant. Reproductive strategies of big sagebrush subspecies have evolved that favor the development of both regional and localized populations.

Sagebrush communities are extremely valuable natural resources. They provide ground cover and soil stability as well as habitat for various ungulates, birds, reptiles and invertebrates. Species composition of these communities is quite complex and includes plants that interface with more arid and more mesic environments.

Large areas of big sagebrush rangelands have been altered by destructive grazing, conversion to introduced perennial grasses through artificial seeding and invasion of annual weeds, principally cheatgrass (*Bromus tectorum* L.). Dried cheatgrass forms continuous mats of fine fuels that ignite and burn more frequently than native herbs. As a result, extensive tracts of sagebrush between the Sierra Nevada and Rocky Mountains are rapidly being converted to annual grasslands. In some areas recent invasions of perennial weeds are now displacing the annuals. The current weed invasions and their impacts on native ecosystems are recent ecological events of unprecedented magnitude.

Restoration of degraded big sagebrush communities and reduction of further losses pose major challenges to land managers. Loss of wildlife habitat and recent invasion of perennial weeds into seedings of introduced species highlight the need to stem losses and restore native vegetation where possible. Initial efforts to stabilize degraded sagebrush communities relied upon the use of introduced grasses. It is now generally recognized that restoration of the structure, functions and values of sagebrush ecosystems requires the use of site adapted species, subspecies and ecotypes. Our ability to accomplish this goal is improving with the use of an increasing numbers of native species and development of seed production and seeding practices for these species.

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Introduction

Big sagebrush (*Artemisia tridentata* Nutt.), the most widely distributed of the 11 sagebrush species in the Intermountain region, also occurs on the western Great Plains in western Montana, Wyoming and Colorado. Seasonal precipitation patterns, elevation gradients and soil conditions regulate the distribution of the three major subspecies of this landscape-dominating shrub.

Basin big sagebrush (*A. t.* Nutt. ssp. *tridentata*), once the most widespread of the three subspecies, is a tall, erect, heavily branched shrub growing 1 to 3 m in height with trunk-like main stems (Cronquist 1994). Plant crowns and heights of the broad panicles are uneven, giving the shrub a ragged appearance. Persistent leaves are narrowly lanceolate and apically 3-toothed. When crushed they emit a pungent, spicy odor (Blaisdell et al. 1982). Basin big sagebrush flowers from late August to October and seeds mature from October to November (McArthur et al. 1979).

This subspecies is common to dominant on plains, in valleys and canyon bottoms and along ditch banks and fence rows in areas below 2,500 m elevation that receive 32 to 36 cm of annual precipitation (Cronquist 1994, Goodrich and Neese 1986, Goodrich et al. 1999, Monsen and McArthur 1984). It normally occurs in sagebrush, rabbitbrush (*Chrysothamnus* Nutt. spp.), juniper (*Juniperus* L.) and pinyon (*Pinus* L.)-juniper communities on deep, productive, well-drained, gravelly to fine sandy loams and deep alluvial soils (Welsh et al. 1987). Many of these areas have been converted to agricultural uses. Some basin big sagebrush populations occur on alkaline soils and form mosaics with salt desert shrubs (McArthur et al. 1979).

Wyoming big sagebrush (*A. t*. Nutt. ssp. *wyomingensis* Beetle & Young) is the most xeric subspecies of big sagebrush, generally growing on shallow, gravelly soil on sites receiving 20 to 30 cm of annual precipitation (Cronquist 1994, Goodrich et al. 1999, Monsen and McArthur 1984). It exhibits a ragged growth habit, similar to that of basin big sagebrush, but most plants are less than 1 m in height. The main stems branch at or near ground level. Persistent leaves are narrowly cuneate to cuneate and emit a pungent odor when crushed (McArthur et al. 1979). Panicles are narrower than those of basin big sagebrush. Flowering occurs from late July to September and seeds mature in October and November.

Common throughout much of the Intermountain area, Wyoming big sagebrush also occurs east of the Continental Divide in Montana, Wyoming, and Colorado. It is most abundant at low to moderate elevations, but may be found at elevations up to 2,700 m in sagebrush, rabbitbrush, salt desert shrub, juniper and bitterbrush (*Purshia tridentata* [Pursh] D.C.) communities (Cronquist 1994, Welsh et al. 1987).

Mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle), like Wyoming big sagebrush, is normally less than 1 m in height, but some low elevation plants may be 2 m tall. Main branches divide near the ground and sometimes layer. Unlike the other two subspecies, the crown and inflorescence branches of Wyoming big sagebrush are of uniform height, giving the plant a spreading to rounded outline. Persistent leaves are broadly cuneate and spatulate and emit a sweet, camphor or mint-like odor (McArthur et al. 1979). Panicles are narrow and dense. Plants bloom in July and seeds mature from September through October (McArthur et al. 1979). Mountain big sagebrush occurs at elevations from 800 to 3,200 m on sites receiving more than 30 cm of annual precipitation (Cronquist 1994, Goodrich et al. 1999, Monsen and McArthur 1984). It grows on well-drained, slightly alkaline to slightly acid soils in plant communities ranging from sagebrush-grass to aspen (*Populus tremuloides* Michx.) to spruce (*Picea* Link.)-fir (*Abies* Hill.) (Sampson and Jesperson 1963, Welsh et al. 1987).

All subspecies of big sagebrush are considered topographic and edaphic climax dominants. Their ability to differentiate and adapt to the widely varying and continuously changing habitats of the Intermountain region is attributed, at least partially, to development of polyploid populations capable of surviving in drier habitats (McArthur 2000). In addition, hybridization between overlapping taxa and populations of this wind pollinated species produces new genetic combinations, thus expediting the occupation of available niches.

Several adaptive features influence the distribution and persistence of big sagebrush subspecies. These include variation in growth habit, root system development, response to fire, the ability to conduct photosynthesis at low temperatures and the production of allelopathic substances in roots and leaves that decrease the respiration of associated species and provide a chemical defense against herbivory (Blaisdell et al. 1982, Kelsey 1986a, Kelsey 1986b, Petersen 1995). Additional adaptive features include seed germination capabilities over a wide range of temperatures, unusual seed dispersal strategies, seed size and structure and timing of seed maturation (Blaisdell et al. 1982, Kelsey 1986a, Kelsey 1986b, Meyer and Monsen 1992, Petersen 1995).

Prior Use and Status of Big Sagebrush Communities in the West

Extensive disturbances have occurred throughout big sagebrush communities of the western United States. Degradation began soon after domestic livestock were introduced into the region beginning in the 1840's (Young et al. 1979). Grazing occurred throughout a wide range of plant associations at various elevations and in areas characterized by differing climatic regimes. Grazing was particularly disruptive in big sagebrush communities as use was imposed during spring and fall periods when forage quality and accessibility of these communities are generally greater than for upland communities, but when plants are most susceptible to damage. Consequently, herbaceous understory species associated with big sagebrush vegetation received concentrated and repeated heavy use, which reduced their vigor and ability to recover (Houston 1961). The duration of favorable temperature and soil water conditions for growth in spring is highly variable in sagebrush communities (Hanson et al. 1986). Thus in dry years, grazed plants were often further stressed, hastening the decline of the more palatable species.

Grazing also disrupted ecological processes associated with natural succession (Blaisdell et al. 1982), facilitating the invasion of annual weeds (Billings 1994, Mack 1981). Weed infestations, in turn, dramatically increased the frequency of wildfires and further reduced the vitality and integrity of the remaining native communities (Whisenant 1990). Increased fire frequency and aggressive annual weeds combined to displace big sagebrush with the ultimate result that extensive areas of shrub and perennial grass communities were converted to annual grasses (Bunting 1985, Piemeisel 1951). Pellant and Hall (1994) and Sparks et al. (1990) reported that more than 1.3 million hectares in Nevada, Oregon, Utah, Washington, and Idaho were occupied by cheatgrass (*Bromus tectorum* L.) and medusahead wildrye (*Taeniatherm caput-medusae* L.), while another 30.8 million hectares were classified as infested and susceptible to invasion by these two annual grasses.

Serious disturbances were created by livestock grazing in numerous other western plant communities at the same time big sagebrush sites were being impacted. Numerous high elevation watersheds were severely degraded by grazing as early as 1880 (Ellison 1960). This created such serious downstream problems that attention became focused on the restoration of aspen and mountain herbland communities. The importance of stabilizing high elevation watersheds prompted the selection of species that could provide immediate and permanent protective ground cover (Sampson 1921). As might be expected, the native species tested exhibited erratic establishment, due, in part, to inexperience and inappropriate planting techniques. Scientists and land managers discovered that various introduced perennial species, principally grasses, established quickly and provided uniform ground cover on exposed soils as well as palatable forage for livestock (Forsling and Dayton 1931).

Based on successes in high elevation watersheds, land managers accepted and began to use a number of introduced perennial grasses to stabilize disturbances in other plant communities (Meeuwig 1965). The introduction of exotic forage species to replace understory bunchgrasses on low elevation shrublands quickly became a common practice (Hull and Holmgren 1964, Plummer et al. 1955). In addition, a number of early surveys and inventories of western lands recommended conversion of shrub communities to introduced forage species (Williams 1898).

Many native plant communities, principally big sagebrush types, were converted to introduced perennial grasses and managed specifically for seasonal grazing by livestock (Hull 1971, Pechanec et al. 1944, Plummer et al. 1955). Land managers and private landowners accepted the concept that conversion of big sagebrush communities to introduced grasses would not only provide persistent cover, acceptable forage yields, and improved seasonal forage quality and availability, but would also control weeds and enhance wildlife habitat and watershed quality. Breeding and plant selection programs were instigated to develop introduced species as forage plants for big sagebrush communities (Johnson 1980, Johnson et al. 1981).

Later observations and studies of seeded watersheds and rangelands, including big sagebrush sites, began to indicate that introduced grasses were not compatible with native communities (Walker 1999). Their presence reduced the survival of remnant native species, restricted natural recruitment and changed the composition of entire communities. Seeding crested wheatgrass *(Agroypron cristatum* [L.] Gaertner), intermediate wheatgrass (*Elymus hispidus* [Opis] Meld) and smooth brome (*Bromus inermis* Leysser) directly with big sagebrush has prevented shrub seedlings from establishing (Richardson et al. 1986). Mature stands of these grasses also prevented natural recruitment of antelope bitterbrush (Monsen and Shaw 1982) and big sagebrush (Meyer 1994). Frischknecht and Bleak (1957) reported that seeded bluebunch wheatgrass (*Elymus spicatas* [Pursh] Gould) stands were more likely to permit sagebrush seedling recruitment than were crested wheatgrass stands. Seeding introduced grasses on big sagebrush sites occupied with some native perennial herbs and shrubs have resulted in the conversion of mixed assemblages of species to a predominance of introduced species. This conversion process has continued over a nearly 30-year period in some areas (Walker 1999). Its progress is influenced by climatic conditions as well as by livestock and wildlife use.

Livestock grazing, weed invasion, wildfires, and plant conversion projects have all negatively impacted wildlife habitats in big sagebrush communities (Dobler 1994; Workman and Low 1976). The high nutritional quality and variety of forbs and shrubs present in native communities is vital for maintaining wildlife diversity (Dietz and Negy 1976, Memmott 1995, Yoakum 1978). Many important shrubs, suffrutescent species, and broadleaf herbs that were critical to wildlife, particularly during winter periods were reduced (Updike et al. 1990) or lost. Declines or losses of species that furnish habitat for numerous wildlife species occurred throughout the sagebrush zone (Monsen and Shaw 1984, Peterson 1987, Shaw et al. 1999, Workman and Low 1976). A rapid and continued decline in populations of small mammals, raptors, sage grouse (*Centrocercus urophasianus*) (Connelly and Braun 1997), songbirds (Saab and Rich 1997), and other vertebrates and invertebrates has also occurred throughout big sagebrush communities of the West, particularly in the past 20 to 40 years.

The use of woody and herbaceous plants to restore wildlife habitat began prior to 1930 in several western states (Brown and Martinsen 1959, Holmgren 1954, Hubbard et al. 1959). By 1950 native species were being used to revegetate mined sites, roadway disturbances, parks and natural areas. The demand for site-adapted material prompted the collection and planting of some native species, but demands were small compared to those for seeds of introduced species used for rangeland and watershed seedings. During the 1950s the demand for native species for a wide range of sites grew rapidly.

A major increase in mining activities occurred in the western United States beginning in the mid 1960's. Open pit mining for coal provided a major source of income from areas previously used primarily for grazing. At the same time, public demand for revegetation of human-caused disturbances began increasing (Monsen and Plummer 1978, Wieland et al. 1971). Regulations were adapted to insure that disturbances were regraded, topsoiled and planted to a mixture of species that existed on the site prior to mining. Concern for proper revegetation of mined sites soon expanded to include roadways, pipelines and related disturbances (Megahan 1974). Native species were now considered valuable for providing ecologically stable communities.

In 1958 the Utah Fish and Game Department began funding a cooperative study with the USDA Forest Service to develop the ecological database and technology required to improve big game habitats in Utah. The initial emphasis was on pinyon-juniper woodlands and big sagebrush communities (Plummer and Jensen 1957). Major objectives were to reestablish shrub and forb communities, thus emphasis was shifted to a new suite of species (Monsen 1989). Reliance upon introduced grasses was reduced, and research was directed toward the development of technology required to harvest, process and plant native shrubs and forbs. This project ultimately provided the scientific basis and methodology for revegetating shrub-dominated communities in Utah and surrounding states (McArthur 1988). Large acreage of private, state and federal lands were planted with site-adapted species, and the work is ongoing. Based on demands for seeds of native species generated by this and other public and private revegetation efforts, the native seed industry underwent rapid growth (McArthur and Young 1999).

Perhaps the single most important issue that has emerged to promote the re-establishment of native communities, particularly big sagebrush sites, has been the spread of weeds throughout the West. One of the most troublesome species is cheatgrass *(Bromus tectorum* L.), a cool season winter-annual grass. Cheatgrass and several other annual weeds were first reported in about 1900, but spread rapidly and occupied large areas within 10 to 30 years (Platt and Jackman 1946). Other equally troublesome weeds, including numerous perennials, were introduced later, but now present serious problems (Roche and Roche 1988). Many disturbances were initially planted to introduced perennial grasses as they developed rapidly and were able to compete with the annual weeds (Monsen 1994). Seeding exotic perennials to contain exotic annuals proved successful initially, but the resulting stands did not provide the structure, functions, resilience or values of the native communities.

A new generation of weeds is now emerging; some are capable of invading existing stands of exotic perennial grasses as well as some native communities (Sheley and Petroff 1999). This new group includes such aggressive weeds as the knapweeds *(Centaurea* L. spp.) and rush skeletonweed (*Chondrilla juncea* L.) (Liao 1996), some of which are capable of invading and displacing annual weeds, including cheatgrass. Re-establishing communities of native species appears to be the most ecologically sound means of containing these weeds.

Advancement of Native Plants

Acceptance

The evolution of the native seed and plant industry has been totally dependent upon the demand for these species. Some native species have been planted for over 50 years, but only a fraction of all native species are currently in use. Sufficient amounts of big sagebrush seeds are collected annually from wildland stands to plant many large disturbances, including portions of the 0.6 million hectares that burned in Nevada and other western states in 1999. However, only small quantities of many other species are collected each year. Nonetheless, a number of additional species native to big sagebrush communities are becoming more available (McArthur and Young 1999).

Land managers have recognized the need for locally adapted species and ecotypes and appropriate planting technology for each. Studies of ecotypic variation have provided site requirement data and facilitated the development of seed transfer guidelines for some commonly collected shrub and herb ecotypes (Shaw and Roundy 1997). Research has also provided a better understanding of the seedbed conditions required to establish big sagebrush and other species, thus increasing the opportunity to create seedbed microenvironments and devise seeding schedules that maximize the opportunity for establishment of uniform stands (Boltz 1994, Meyer 1994, Roundy 1994). Although an increasing number of native species are being used, many species needed for the restoration of entire communities have only rarely, or more often, never been planted. In addition, our understanding of species relationships and planting practices required to restore communities to a complete assemblage of adapted species at ecologically compatible densities and patterns is poorly developed.

Seed prices are generally quite high as species first come into use. Suppliers realize that extremely expensive seed lots will likely not be purchased. Consequently they tend to provide species that can be sold, yet provide a satisfactory profit. Obviously, costs to collect or produce and clean many species may remain quite high, due to unusual seed characteristics. However, as demand grows, increased emphasis is generally given to the development of improved collection, production, and cleaning techniques, often resulting in increased availability, higher quality, and lower prices (Stevens et al. 1996). Many native species that are urgently needed to restore shrublands are not available in sufficient amounts from wildland collections; consequently field production protocols are being developed to grow the required quantities of seed.

Research and Development

Various federal and state agencies have organized projects to study the ecology and seed and seedling biology of selected native species in order to develop guidelines for their use in revegetation projects (Shaw and Roundy 1997). Research conducted to facilitate the initial use of many native species on mine sites, roadways, recreation sites, and similar disturbances have ultimately benefited many other users.

The USDA Forest Service, Shrub Sciences Laboratory and the Utah Division of Wildlife Resources have conducted cooperative research for more than 40 years. Efforts have centered the on studying the ecology and use of native shrubs and herbs for revegetating range and wildlife habitats. The long-term commitment to this effort has resulted in the release of over a dozen native cultivars and the development of data required to make over 100 species available for use by the commercial seed industry (McArthur and Young 1999).

State and federally funded research has been instrumental in encouraging the collection and study of native species. Research has been directed toward defining the areas of adaptation of populations or ecotypes within individual species. Plant materials have been assembled to better define the adaptive characteristics that may limit species or ecotypes to specific sites, climatic regions, or soil conditions (Monaco 1996). Sufficient differences have been noted among populations or ecotypes of individual species that users should be cautioned against moving plant materials outside their area of adaptation.

A limited number of studies have been conducted to determine the genetic relationships among species, subspecies, and populations and the nature of genetically controlled characteristics. Collections of selected species have been assembled to permit comparisons of specific characteristics such as herbage production, drought tolerance, seedling vigor and related attributes that may enhance their use. A principal concern is the maintenance of genetic diversity within a population when seeds are grown under cultivation. Guidelines for retaining genetic integrity must be developed for native species grown in seed fields to avoid shifts in genetic characteristics if some plants may be favored or eliminated during field production.

Research has also been conducted to determine the agronomic characteristics of potential revegetation species and ecotypes. Of greatest concern are the germination and seedling establishment characteristics of each plant. Considerable variation has been found to occur in seed dormancy, germination patterns, and growth characteristics among different collections and populations (Meyer and Monsen 1990, Shaw 1994). Germination patterns are genetically regulated and have evolved to enhance survival under different climatic regimes (Meyer and Monsen 1992). Seeds of different species and populations require specific micro-environmental seedbed conditions for germination and establishment. Determining specific requirements for individual species and populations is essential for developing appropriate seedbed preparation and planting techniques and equipment (Monsen and Meyer 1990, Shaw 1994).

A site-identified certification program to verify and certify the origin of wildland-collected seeds was recently developed and accepted by the Association of Official Seed Certifying Agencies (Young 1994). This program provides a system for inspection, labeling, and certification of specific collections. Seed collections are inspected in the field by qualified state seed certification agency personnel who tag individual seed lots and maintain records to assure that seeds are sold with proper data on the site of origin.

Development of Wildland Harvesting, Cleaning, and Storage Practices

Although the development of technology to harvest, clean, and plant the seeds of species native to sagebrush communities is often not recognized as a major issue, development of this information is extremely critical. Most conventional seed harvesting equipment is not capable of harvesting many native species. In addition, existing seed cleaning equipment used for agronomic species has not been completely satisfactory for cleaning some native seeds. Consequently, funding by federal and state agencies has been required to develop new equipment or modify existing equipment for harvesting and cleaning wildland seeds. Competition for seed sales has compelled native seed collectors and growers to assume a role in these endeavors. Although the costs required developing new harvesting and cleaning equipment often exceed the capabilities of individual companies, modifications and improvements of existing equipment have considerably streamlined harvesting and improved the quality of the seed lots marketed.

Research has been conducted to develop safe and effective techniques for cleaning and planting seeds of species that present unusual difficulties. Some seed lots are difficult and costly to clean; others are easily damaged during the cleaning process. Removal of seed coats or other appendages from seeds of some species may decrease seed germinability and seedling survival. The condition of individual seed lots directly affects the metering of seeds through conventional drills and seeders. Consequently, safe and efficient techniques must be developed for cleaning each species.

Development of Seed Germination and Quality Standards

Development of seed germination and quality standards is essential for the marketing of native seeds. Standard testing procedures are essential to aid buyers in determining the quality and value of individual lots. Federal and state agencies have conducted studies to develop germination procedures for individual species for use by state seed testing laboratories. Purity and other tests of seed quality are also being standardized.

Seed Warehousing

A high percentage of native seed sales are made to either state or federal agencies. Sales of some species are dependent on annual collections from wildland stands; consequently their availability varies considerably. To reduce this uncertainty in seed supply, the Utah State Division of Wildlife Resources (Utah DWR) and the USDI Bureau of Land Management in Idaho (Idaho BLM) have each constructed and manage seed warehouses. The BLM warehouse handles seeds for plantings in much of the western United States. At each location, seeds are acquired in advance to ensure their availability when planting begins. The DWR distributes a list of seeds and seed sources required on an annual basis.

Advanced seed purchasing and warehousing has added stability to the native seed industry as collectors are aware of the species and amounts of seeds required at the beginning of the field season and can plan their harvest accordingly. Many other agencies, private companies, and contractors who enter into cooperative plantings with the Utah DWR and Idaho BLM also benefit from the seed warehousing program. In addition, these programs have improved the availability of numerous species, making them available to other buyers. The result has been a much more rapid advancement of the native species program than would otherwise have been expected. The use of adapted ecotypes has increased, and in some cases seed prices have been reduced.

Both the Utah DWR and Idaho BLM have hired and trained individuals to manage these seed warehouse facilities. These individuals are involved in the development and execution of revegetation projects and monitoring programs to assess planting success. This combined responsibility has greatly increased the tracking of seed quality, improved seed storage techniques, and increased the use of adapted species and ecotypes. More thorough monitoring of seeding success permits feedback to improve the success of future plantings.

The DWR has developed seed quality standards and they set maximum acceptable seed prices for individual species each year. Seeds are often stockpiled during good harvest years. Seed companies quickly recognized that seeds of some species harvested from wildland stands were costly and supplies often unreliable, consequently some progressive companies began raising seeds under cultivation, thus improving seed availability and reducing prices.

Development of Site Preparation and Planting Practices

A primary challenge to the use of native seeds was the development and use of successful planting practices. This required the development of equipment to seed trashy seeds and seeds with unusual morphological characteristics. Private contractors and companies normally do not have the resources to research and develop suitable equipment. A concentrated effort has been required to address these problems. The development of seeding and related equipment for range and wildlands use is often not attractive to large equipment companies as equipment sales are normally quite low compared with sales of conventional agricultural equipment. However, small machinery companies have often been instrumental in developing and modifying equipment to solve specific problems. A small Utah company, for example, developed the “Hansen Seed Dribbler” which permitted planting seeds of different shapes and sizes. This machine completely revolutionized shrub seeding.

The Range Technology and Equipment Committee

An independent committee was organized in 1944 to help advance the development of equipment needed to revegetate rangelands. This organization, now known as the Range Technology and Equipment Committee (RTEC) has been successful in soliciting funds from state and federal agencies to develop and construct harvesting, cleaning and seeding equipment. In addition, the group has published and distributed proceedings, manuals and reports to advance revegetation technology.

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